RESEARCH DEPARTMENT

U.H.F. relay station aerials inside 914 mm diameter glass-fibre cylinders

TECHNOLOGICAL REPORT No. RA-16

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THE BRITISH BROADCASTING CORPORATION
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RESEARCH DEPARTMENT

U.H.F. RELAY STATION AERIALS INSIDE 914 mm DIAMETER GLASS-FIBRE CYLINDERS

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SUMMARY

The BBC aerial for u.h.f. relay stations was designed for operation inside a glass-fibre cylinder of 387 mm diameter. More recently a new requirement has arisen to house the aerial inside a 914 mm diameter cylinder to permit access. An investigation was therefore carried out to study the effect of a 914 mm cylinder on the performance of the aerial. A position of the aerial inside the larger cylinder was found which would achieve acceptable horizontal radiation patterns at some relay station sites but would not have universal application.

1. INTRODUCTION

The BBC transmitting aerial for u.h.f. relay stations[1] was designed for operation inside a glass-fibre cylinder having an internal diameter of 387 mm and a wall thickness of approximately 8 mm. It has been proposed that a 914 mm diameter cylinder should be used in the future because it is considered that physical access through the cylinder is desirable for aerial maintenance and to provide a better way of maintaining an obstruction light at the top, should one ever be required. An obvious way of meeting this new requirement would be to mount the existing aerial inside the larger cylinder.

When the requirement arose, the effect of the larger cylinder on the performance of the aerial was not known, although it was appreciated that critical positioning would probably be necessary to preserve the impedance bandwidth. Some preliminary calculations, however, indicated that considerable distortion of the horizontal radiation pattern (h.r.p.) was to be expected for aerial positions away from the cylinder axis and that unacceptable variations with frequency could also occur. A comprehensive series of measurements was therefore carried out to establish the effect of a 914 mm cylinder on the horizontal radiation pattern and impedance with the aim of finding a position and orientation of the aerial within the cylinder which achieved a workable compromise.

2. THEORY

To initiate the work, a series of calculations was carried out on the computer to find the effect of a dielectric cylinder on the radiation pattern of a dipole lying parallel to the axis but offset from the centre by an arbitrary distance. The theory is based on Carter's reciprocity method[2] and postulates a plane wave coming from a doublet source at a great distance from the cylinder. The field due to it is calculated in the cylindrical system (see Fig. 1) and the principle of reciprocity is then used to interchange source and field points. The details

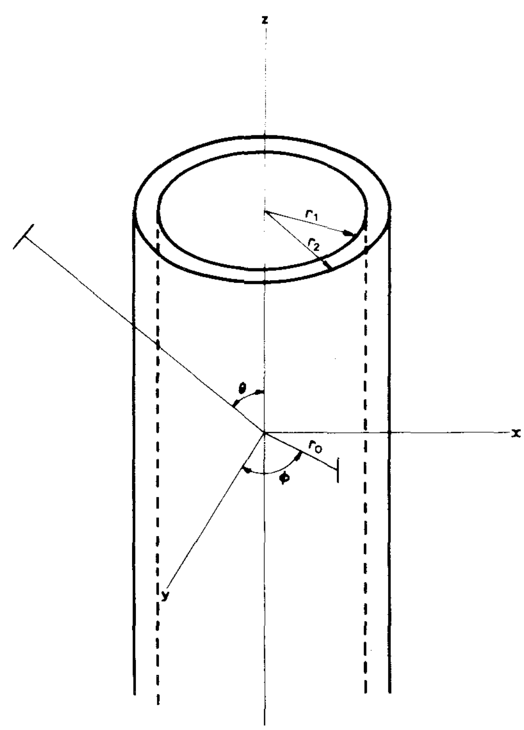

Fig. 1 - Geometry of dielectric cylinder and vertical doublet

are given in Appendix I. Some results of the computations are shown in Figs. 2 and 3. The magnitude of the radiated electric field is plotted in Fig. 2 for a dipole positioned along the $\phi = 0°$ radial at radii of 0·2 and 0·6λ within a cylinder which has an inner radius of 1λ, a thickness of 0·03λ and a dielectric permittivity of 4·5. These values correspond to an aerial radiating at 655 MHz inside a 914 mm diameter glass-fibre cylinder of wall thickness 12·7 mm. With the dipole placed axially in the cylinder, the radiation pattern is clearly omnidirectional. It is immediately evident from Fig. 2, however, that as the dipole is moved away from the axis, the dielectric cylinder is having a considerable effect. The greater the value of r_0, the more ripples appear in the pattern.

Fig. 3 shows the effect at $r_0/r_1 = 0·2$ and 0·6 of halving the frequency so that the inner radius of the cylinder is now 0·5λ and the wall thickness 0·015λ. Considerably less distortion of the omnidirectional pattern occurs; the maximum/minimum ratio is reduced from 9·4 dB to 5·5 dB at $r_0/r_1 = 0·6$.

In general, as the radius in wavelengths of the dielectric cylinder is increased, the radiated fields are proportionately more affected by the presence of the cylinder, all other parameters being held constant. For cylinder radii less than about 0·5λ the distortion of the pattern is not serious. The radius of a 381 mm diameter cylinder varies between 0·3λ and 0·54λ so that very little change in the free-space radiation pattern would result. This is confirmed by previous measurements[1].

3. PATTERN MEASUREMENTS

The theoretical study outlined in Section 2 indicated the need for a further investigation. It was therefore decided to measure the patterns of a half-aperture relay-station aerial inside a 6·09 m length of cylinder. The inside diameter of the length of cylinder was 914 mm and wall thickness 9 mm. For this cylinder the radius varies from 0·7λ at the lower end of Band IV to 1·3λ at the upper end of Band V, thus considerable distortion of the h.r.p. might be expected.

The glass-fibre cylinder was mounted vertically on a large turntable (Fig. 4). Three aerials were used; an 8λ upper half-aperture aerial for Channels 39 – 52; a similar aerial for Channels 53 – 68 and a 4λ aerial for Channels 21 – 34. These could be positioned so that the dipole elements and support channel lay on a diameter at any distance from the cylinder wall (Fig. 5). The spacing of the aerial elements from the cylinder wall as used in subsequent sections is as shown in Fig. 6. Measurements were made at the edges and centre of the frequency band of each aerial, namely at 470, 522 and 580 MHz for Band IV; 615, 670, 725 MHz for lower Band V and 730, 790, 850 MHz for upper Band V. The effect of including a glass-fibre ladder section in the cylinder was also checked, but this was found to be negligible.

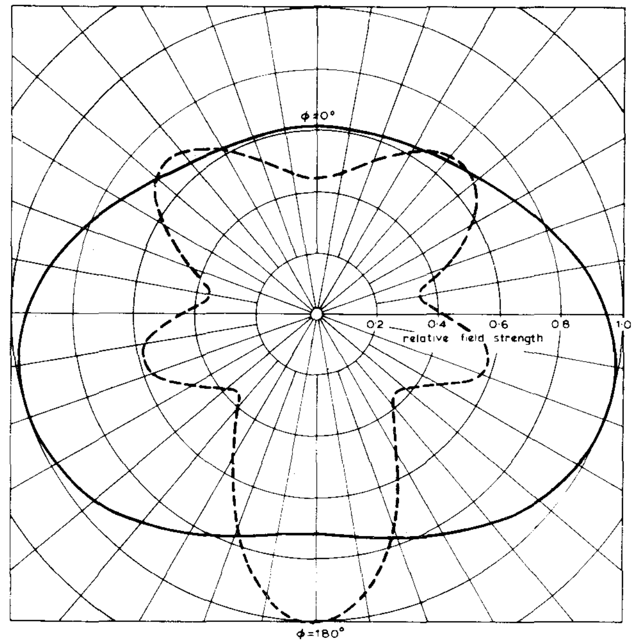

Fig. 2 - Theoretical horizontal radiation pattern for a glass-fibre cylinder of inner radius 1λ
——— $r_0/r_1 = 0·2$ – – – – $r_0/r_1 = 0·6$

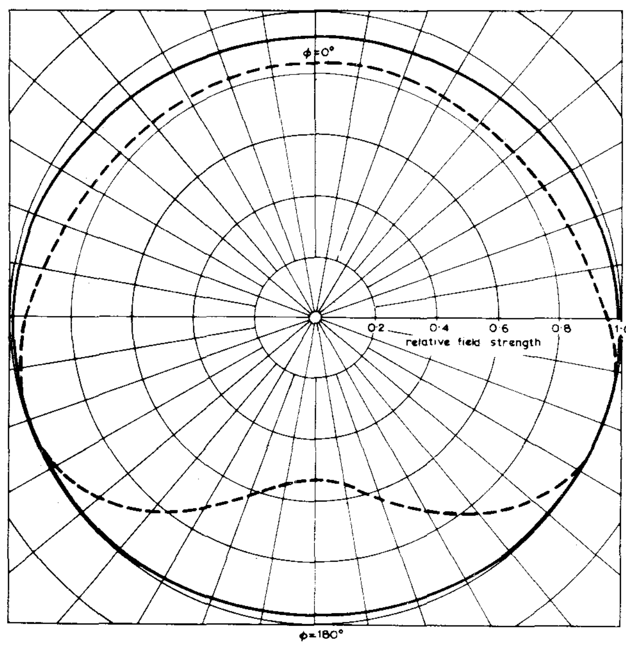

Fig. 3 - Theoretical horizontal radiation pattern for a glass-fibre cylinder of inner radius 0·5λ
——— $r_0/r_1 = 0·2$ – – – – $r_0/r_1 = 0·6$

4. IMPEDANCE MEASUREMENTS

Reflections inside the cylinder affect the input impedance of an aerial, as well as the radiation

pattern. The impedance of a simple vertical dipole is affected most when it is positioned axially and least affected when near one of the walls. This is the reverse of the effect on radiation patterns. It was therefore important to investigate the impedance of the aerials in the 914 mm cylinder because of the possibility that a position for acceptable radiation patterns might coincide with a high value of reflection coefficient. Reflection coefficient measurements were carried out at most of the positions in the cylinder where the radiation pattern was measured, using a Rohde and Schwarz 'Polyskop' and a bridge-detector. The lengthy task of measuring the complex impedance/frequency characteristic of the aerial at the different positions inside the cylinder was not undertaken owing to shortage of time.

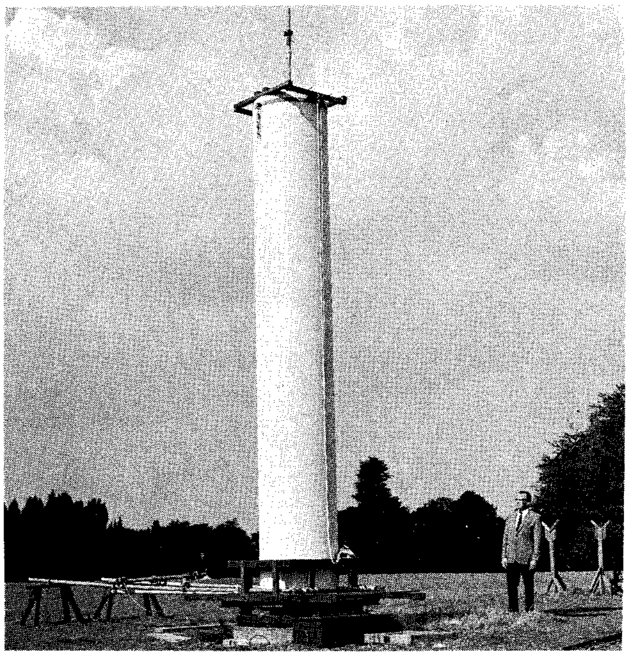

Fig. 4 - General view of 914 mm diameter glass-fibre cylinder on turntable

5. ASSESSMENT OF MEASUREMENTS

5.1. General Requirements

Three principle requirements were assumed when assessing the measurements. Firstly that the h.r.p. should be reasonably smooth and without deep minima, secondly that the variation in radiated field between channels should not exceed 2 dB, and lastly that the impedance mismatch should be fairly constant over the band, having a reflection coefficient modulus of less than 8% at the centre frequency[1]. The h.r.p. for the lower Band V aerial in the 381 mm diameter cylinder is shown in Fig. 7. This is very similar to the free-space pattern. Ideally the h.r.p. in the 914 mm cylinder should substantially meet the templet requirements also shown in Fig. 7.

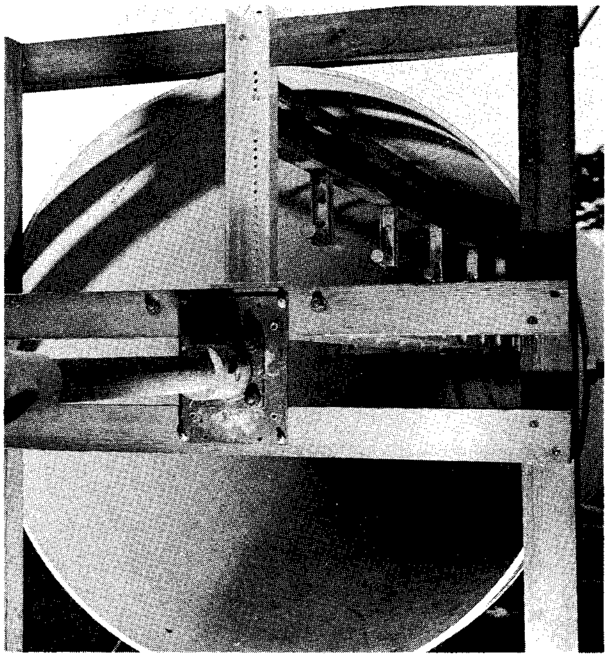

Fig. 5 - An aerial positioned inside the 914 mm diameter glass-fibre cylinder

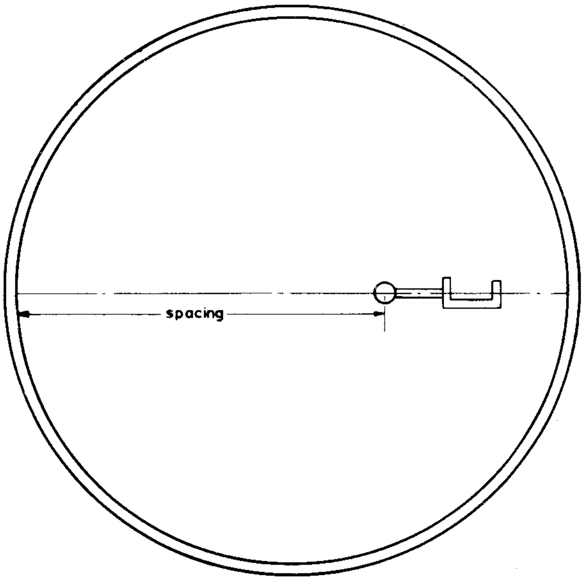

Fig. 6 - Position of aerial inside cylinder

5.2. Dipole Elements at Centre of Cylinder

When the aerial elements are near the axis of the cylinder, the patterns are smooth and do not exhibit deep minima (Figs. 8, 9, 10). The Band IV pattern is at 533 mm spacing, the other two at 446 mm and 457 mm respectively (the spacing is that measured from the centre of the dipole, along a diameter, to the cylinder wall, see Fig. 6). In the Band IV range, however, the pattern spreads out with increasing frequency giving a variation between channels of about 4 dB over a total arc of about

60°. The reflection coefficient for the lower Band V aerial at this spacing is plotted in Fig. 11. This curve exceeds the permissible values at all frequencies in the band[1].

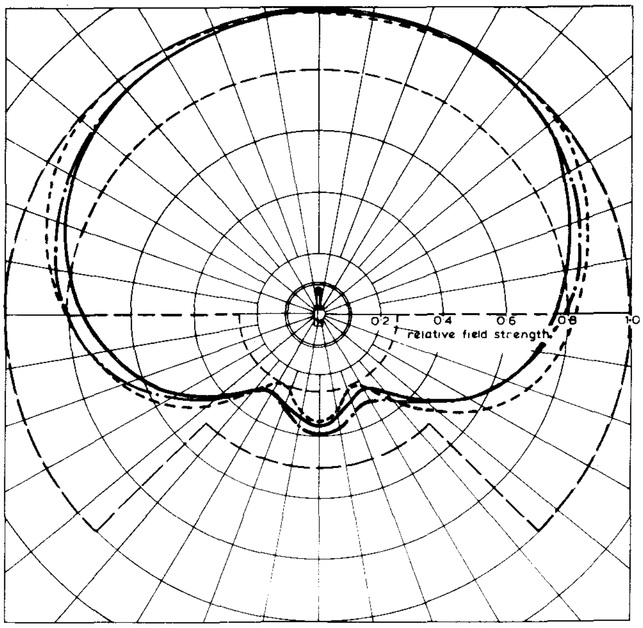

Fig. 7 - Measured h.r.p.s of lower Band V aerial in 387 mm diameter cylinder and maximum and minimum required field strength
— — 615 MHz ——— 670 MHz - - - - - 725 MHz

5.3. Dipole Elements Near the Cylinder Wall

When the aerial elements are within a few inches of the cylinder wall, patterns are obtained where the variation with frequency in each band is acceptable (Figs. 12, 13, 14) except over a small arc. The reflection coefficient for 25·4 mm spacing (Fig. 11), is acceptable but it is necessary to position the aerial critically for each band. Over a small arc of about 40° at the back the field strength falls below the requirement and a deep minimum appears on all bands. Within this minimum the variation of effective radiated power (e.r.p.) from one channel to another is excessive so that the aerial is not suitable for stations where a service is required in all directions.

5.4. Support Channel Near Cylinder Wall

When the supporting channel section is near to the cylinder wall the variation of e.r.p. with frequency is large (Figs. 15, 16, 17) and considerable distortion of the pattern is evident.

5.5. Dipole Elements in Other Positions

For positions of the radiating elements between the centre of the cylinder and the walls, all the patterns are vary variable and do not meet the templet requirement of Fig. 7. (This is true whether the support channel and radiating elements are on the same diameter or not.) Two representative patterns are shown in Figs. 19, 20. The reflection coefficient at intermediate positions is not as bad as when the aerial is positioned near to the centre of the cylinder but it is worse than in free-space, particularly at low frequencies. Fig. 18 shows the reflection coefficient in lower Band V for spacings of 279 mm and 711 mm compared with the free-space conditions.

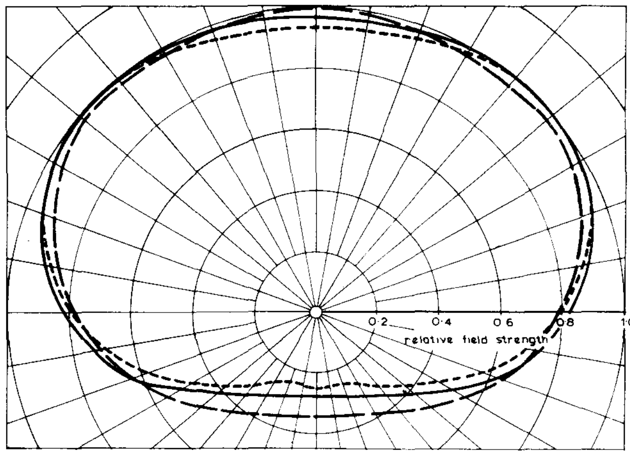

Fig. 8 - H.R.P. of lower Band V aerial in 914 mm diameter cylinder, spacing 446 mm
— — 615 MHz ——— 670 MHz - - - - 725 MHz

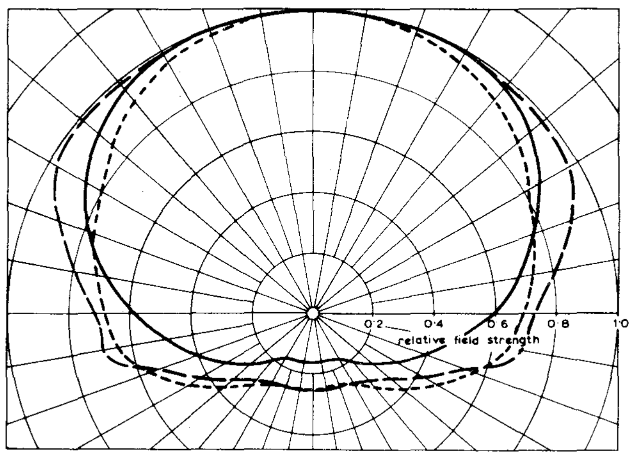

Fig. 9 - H.R.P. of upper Band V aerial in 914 mm diameter cylinder, spacing 457 mm
— — 730 MHz ——— 790 MHz - - - - - 850 MHz

6. SERVICE PLANNING REQUIREMENTS

Aerials for relay stations fall into two categories: the standard type which is used in the majority of cases where a cardioidal pattern, as provided by the BBC aerial in the small 381 mm diameter cylinder, is fully adequate, and the special types which are engineered to give more

highly directional patterns as required at certain stations. The best patterns obtained in the 914 mm diameter cylinder were those where the dipole element was near to the cylinder wall (described in 5.3) and these have been examined in relation to the service requirements of 24 typical relay stations. At two of these the deep minima make the patterns unacceptable, and at four others the patterns would be marginally satisfactory. At the remainder the patterns were satisfactory.

7. POSSIBLE FURTHER WORK

Some consideration was given to possible measures which might be taken in order to reduce the electrical effect of the cylinder. Two proposals are discussed briefly.

7.1. Double-walled Cylinders

It is obvious that, if a concentric inner cylinder of equal wall thickness is introduced such that the mean distance between the walls is one quarter wavelength, then the reflections from both cylinders will tend to cancel one another out. To include a complete inner cylinder would, of course, defeat the object of the larger cylinder by restricting access, but it is possible that a segment of an inner cylinder might be sufficient to achieve acceptable performance without restricting access altogether. Further development, however, would be needed to investigate this possibility.

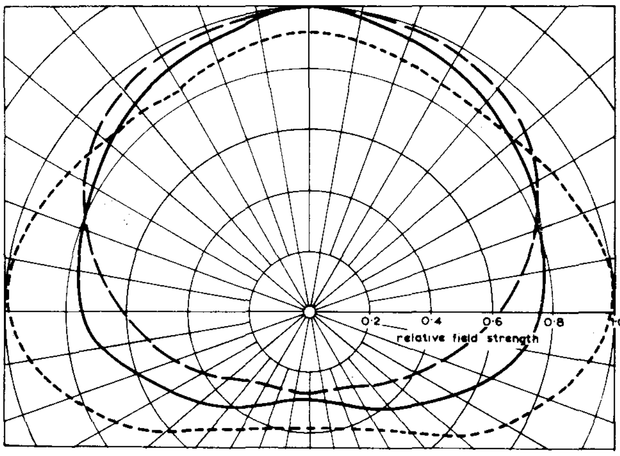

Fig. 10 - H.R.P. of Band IV aerial in 914 mm diameter cylinder, spacing 533 mm
—— 470 MHz ——— 522 MHz - - - - - 580 MHz

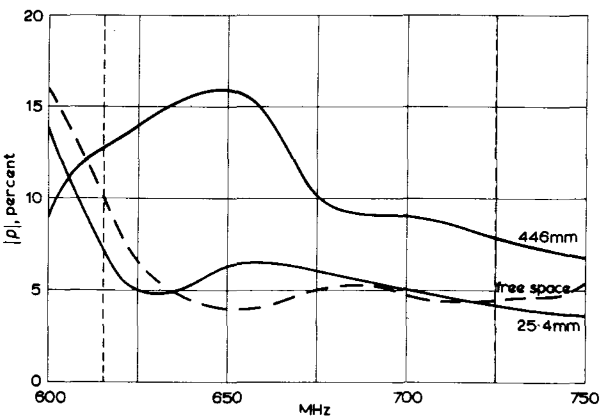

Fig. 11 - Reflection coefficient of lower Band V aerial in 914 mm diameter cylinder, spacings 25·4 mm and 446 mm

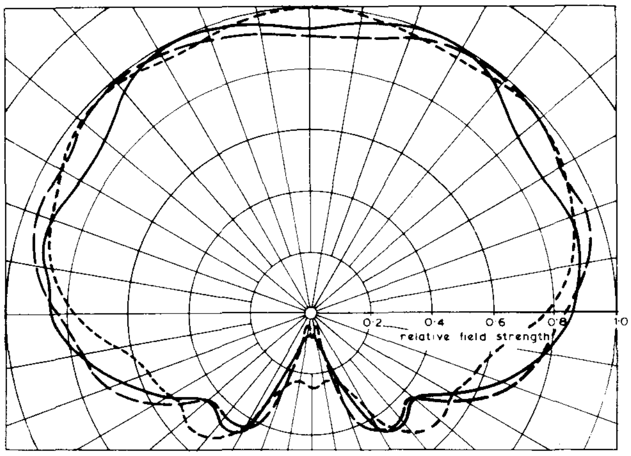

Fig. 12 - H.R.P. of Band IV aerial in 914 mm diameter cylinder, spacing 25·4 mm
—— 470 MHz ——— 522 MHz - - - - - 580 MHz

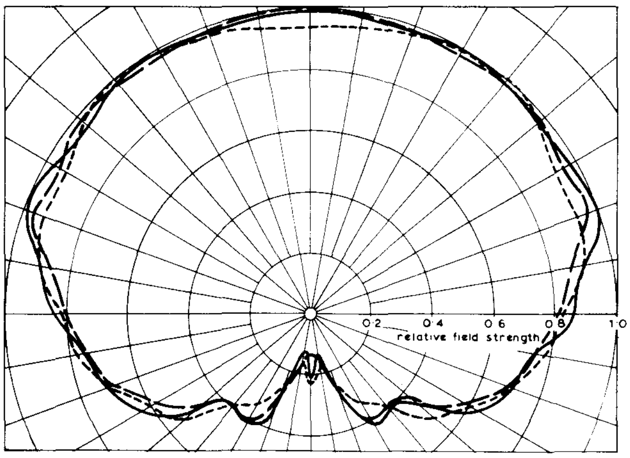

Fig. 13 - H.R.P. of lower Band V aerial in 914 mm diameter cylinder, spacing 25·4 mm
—— 615 MHz ——— 670 MHz - - - - - 725 MHz

7.2. Inductive Gratings

The possibility of tuning out the capacitive impedance of the cylinder with a parallel grating of wires embedded in the dielectric and running longitudinally must be mentioned. In principle, this appears attractive as it is in the nature of a wideband compensation and furthermore would not restrict access. However an estimation shows (see Appendix II) that this is an impractical solution as wires of minute thickness are required to achieve resonance.

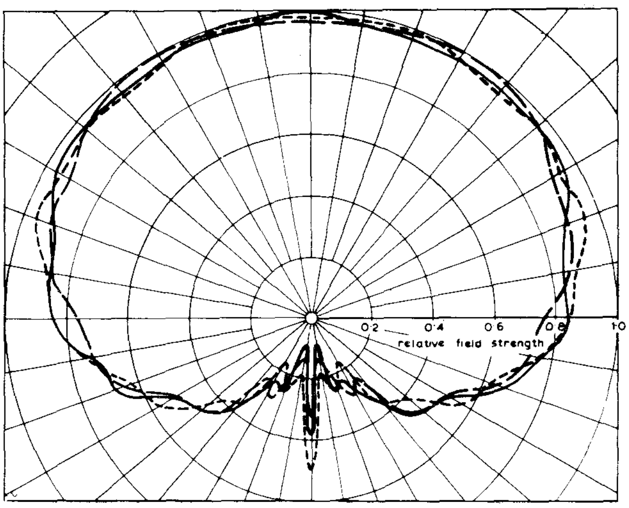

Fig. 14 - H.R.P. of upper Band V aerial in 914 mm diameter cylinder, spacing 25·4 mm

——— 730 MHz ——— 790 MHz ---- 850 MHz

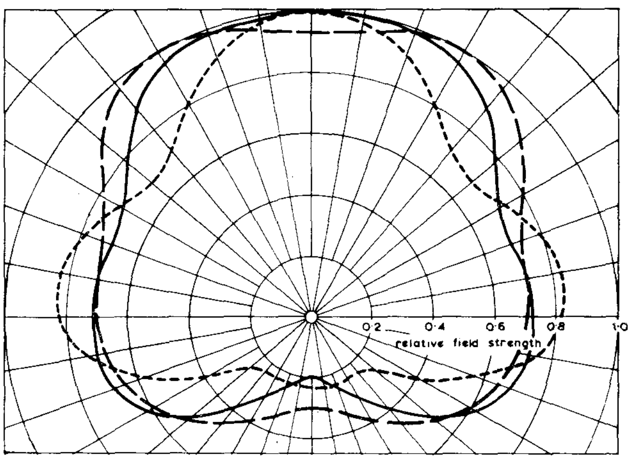

Fig. 15 - H.R.P. of Band IV aerial in 914 mm diameter cylinder, spacing 686 mm

——— 470 MHz ——— 522 MHz ----- 580 MHz

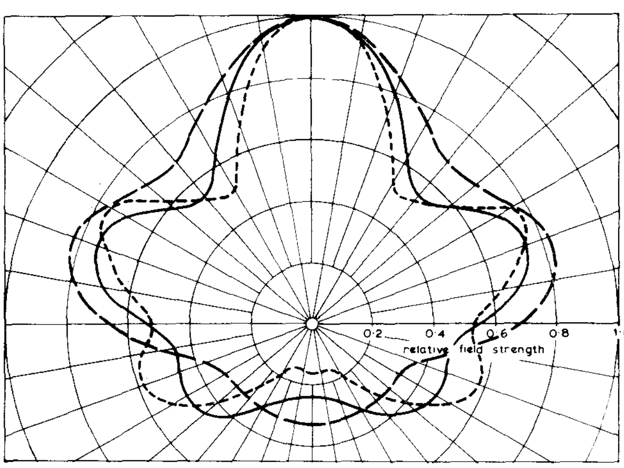

Fig. 16 - H.R.P. of lower Band V aerial in 914 mm diameter cylinder, spacing 711 mm

——— 615 MHz ——— 670 MHz ---- 725 MHz

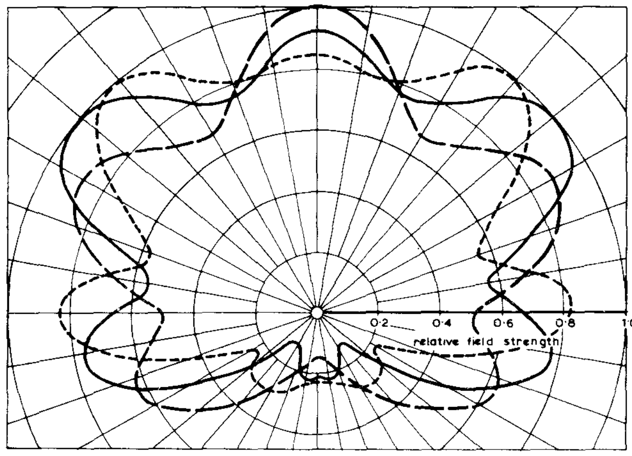

Fig. 17 - H.R.P. of upper Band V aerial in 914 mm diameter cylinder, spacing 674 mm

——— 730 MHz ——— 790 MHz ----- 850 MHz

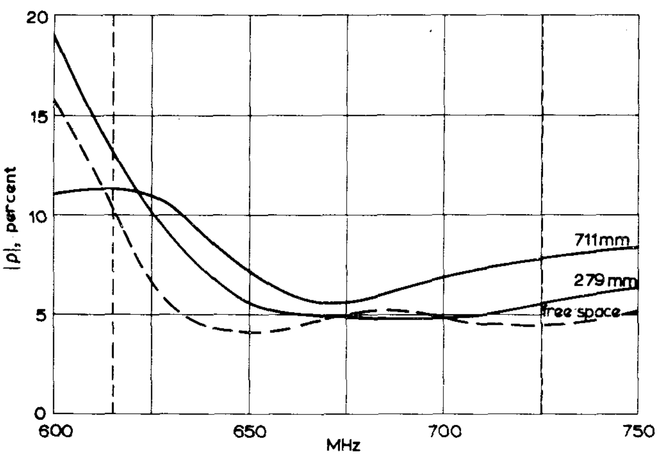

Fig. 18 - Reflection coefficient of lower Band V aerial in 914 mm diameter cylinder, spacings 279 mm and 711 mm

8. CONCLUSIONS

The measurements on the 914 mm cylinder show three principle deleterious effects of the cylinder on the performance of the aerial in any one of the three operating bands. They may be summarized as:

(i) At certain spacings the appearance of deep minima in the h.r.p.

(ii) Unacceptable variations in the e.r.p. between channels in certain directions.

(iii) Serious mismatching.

Although some advantages of immediate access are gained if a 914 mm cylinder is used in future relay stations, because of the above results the present BBC aerial cannot be employed universally inside this size of cylinder. For some relay stations acceptable patterns in Bands IV and V can

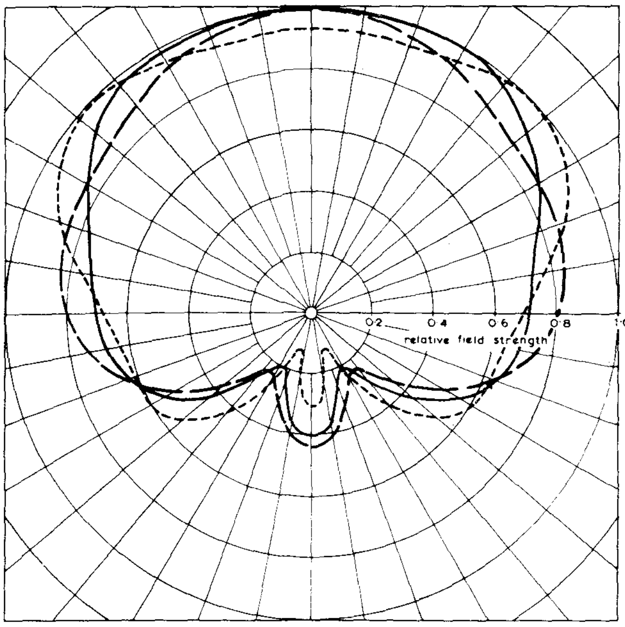

Fig. 19 - H.R.P. of lower Band V aerial in 914 mm diameter cylinder, spacing 280 mm
——— 615 MHz ——— 670 MHz – – – – – 725 MHz

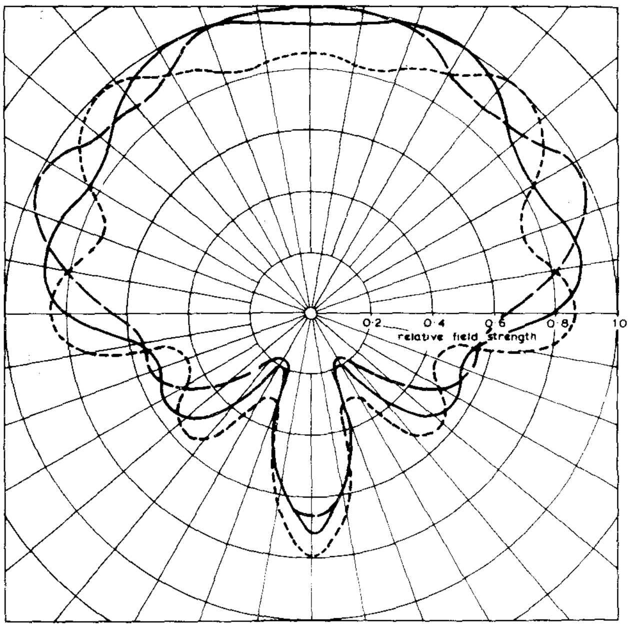

Fig. 20 - H.R.P. of upper Band V aerial in 914 mm diameter cylinder, spacing 146 mm
——— 730 MHz ——— 790 MHz – – – – – 850 MHz

be obtained by critical positioning of the aerial inside the 914 mm cylinder, but each station might need to be designed individually.

A programme of further development work would be necessary to investigate measures for obtaining a performance equivalent to that of the present BBC aerial but inside the larger cylinder.

9. REFERENCES

1. A vertically-polarized transmitting aerial for u.h.f. relay stations. BBC Research Department Report No. E-122, Serial No. 1966/74.
2. CARTER, P.S. 1941. Antenna arrays around cylinders. *Proc.Inst.Radio Engrs.*, 1943, **31**, 12, pp. 671 – 693.

APPENDIX I

The Calculation of Horizontal Radiation Patterns

Carter's method postulates a linearly polarized plane wave propagating in a system of cylindrical co-ordinates. The plane wave is supposed to come from a doublet source at a great distance and the field due to it is calculated in the cylindrical system. The principle of reciprocity is then used to interchange source and field points. The normal to the plane wave front is inclined to the z axis of the cylindrical system at an angle θ. The linear polarization of the plane wave is such that the H_z component of its magnetic field is identically zero. Fig. 1 shows the cylinder with its co-ordinates and the inclination of the plane wave front. The direction of propagation of the plane wave is towards the cylinder. We may consider the E_z component of the incident wave at a point in the $z = 0$ plane with co-ordinates (r, o, ϕ).

If the dielectric cylinder were not present the E_z component of the incident plane wave at this point may be written as

$$E_z = \sin\theta \exp(j\beta r \cos\phi \sin\theta) \qquad (1)$$

where it is understood that the amplitude of the plane-wave field is constant and the electric component is normalized to unity. By means of a well-known expansion, we can express the E_z component of the incident wave as a harmonic series with Bessel function coefficients

$$E_z = \sin\theta \sum_o^\infty \epsilon_n j^n J_n(\beta r \sin\theta) \cos(n\phi) \qquad (2)$$

$$\epsilon_o = 1 \qquad \epsilon_n = 2 \qquad n \neq 0$$

This form is appropriate for manipulations within the framework of cylindrical co-ordinates.

If we now introduce the dielectric cylinder into the system, we will superimpose upon the plane wave a reflected wave from the cylinder which travels outwards to infinity and reflected waves both in the dielectric and the interior of the cylinder producing standing waves. The field in these three regions may be expressed as follows:

1. Exterior of cylinder ($z = 0$)

$$E_z = \sum_o^\infty [\epsilon_n j^n \sin\theta\, J_n(\beta r \sin\theta) + a_n H_n^{(2)}(\beta r \sin\theta)] \cos(n\phi) \qquad (3)$$

The first terms on the r.h.s. result from the incident plane wave and the second terms from the reflected wave, the amplitude of which tend monotonically to zero as r goes to infinity, as required by physical reasoning.

2. Inside the dielectric ($z = 0$), standing waves of the form

$$E_z = \sum_o^\infty \left[b_n J_n(\beta(\bar\epsilon)^{1/2} r \sin\theta) + c_n Y_n(\beta(\bar\epsilon)^{1/2} r \sin\theta)\right] \cos(n\phi) \qquad (4)$$

$$\bar\epsilon = \epsilon/\epsilon_o$$

where ϵ = permittivity of the dielectric

and ϵ_o= permittivity of free space.

3. Inside the cylinder ($z = 0$), standing waves of the form

$$E_z = \sum_o^\infty d_n J_n(\beta r \sin\theta) \cos(n\phi) \qquad (5)$$

which remain of finite amplitude on the axis of co-ordinates.

The discussion so far has been confined to field values at points in the $z = 0$ plane. In order that we may proceed, an extension must be made into the z dimension. It is consistent with excitation by the incident plane wave to state that the z dependence of field components is expressed by means of a factor $e^{j\beta\cos\theta z}$. Then we may use the Maxwell relationships in cylindrical co-ordinates to find

$$H_\phi = -\frac{j}{\eta_o\beta\sin^2\theta}\cdot\frac{\partial E_z}{\partial r} \quad \text{where } \eta_o = \sqrt{\frac{\mu_o}{\epsilon_o}} \qquad (6)$$

and β is chosen to be appropriate to the medium.

The E_z and H_ϕ components are tangential to the walls of the dielectric cylinder and we have a sufficient number of equations to determine the unknown complex coefficients by matching at the cylinder walls. We find

$$\begin{bmatrix} H_n^{(2)}(\beta r_2 \sin\theta) & -J_n(\bar\beta r_2 \sin\theta) & -Y_n(\bar\beta r_2 \sin\theta) & 0 \\ H_n^{(2)\prime}(\beta r_2 \sin\theta) & -(\bar\epsilon)^{1/2} J_n(\bar\beta r_2 \sin\theta) & -(\bar\epsilon)^{1/2} Y_n'(\bar\beta r_2 \sin\theta) & 0 \\ 0 & J_n(\bar\beta r_1 \sin\theta) & Y_n(\bar\beta r_1 \sin\theta) & -J_n(\beta r_1 \sin\theta) \\ 0 & -(\bar\epsilon)^{1/2} J_n'(\bar\beta r_1 \sin\theta) & -(\bar\epsilon)^{1/2} Y_n'(\bar\beta r_1 \sin\theta) & -J_n'(\beta r_1 \sin\theta) \end{bmatrix} \begin{bmatrix} a_n \\ b_n \\ c_n \\ d_n \end{bmatrix} = - \begin{bmatrix} \epsilon_n j^n \sin\theta \, J_n(\beta r_2 \sin\theta) \\ \epsilon_n j^n \sin\theta \, J_n'(\beta r_2 \sin\theta) \\ 0 \\ 0 \end{bmatrix} \quad (7)$$

$\bar\beta = (\bar\epsilon)^{1/2}\beta$

We are only interested in the coefficients d_n here. The crux of the method lies in the recognition that by the application of reciprocity

$$E(\theta,\phi) = \sin\theta \sum_{0}^{\infty} d_n J_n(\beta r_0 \sin\theta) \cos(n\phi) \quad (8)$$

describes the complete radiation pattern of a doublet placed inside the cylinder at a distance r_0 from the axis. The $\sin\theta$ term outside the summation is the pattern factor of the doublet.

In order to obtain the field due to a dipole of any length lying parallel to the cylinder axis it is only necessary to multiply the summation by the appropriate free-space pattern factor. In the special case where $\theta = \pi/2$ the horizontal radiation pattern obtained for the doublet by the above method is identical to that for an infinite line source parallel to the cylinder axis and passing through the point of location of the doublet.

APPENDIX II

The Effect of a Wire Grating

Using approximate expressions

The effective shunt reactance measured between opposite sides of any square of a thin dielectric sheet is

$$Z_1 = \frac{1}{j\omega(\epsilon - \epsilon_0)\Delta}$$

where ϵ = permittivity of dielectric

ϵ_0 = permittivity of free space

Δ = thickness of dielectric

The effective shunt reactance of a grating of thin wires whose spacing is a small fraction of a wavelength is

$$Z_2 = \frac{j\omega\mu_0 d}{2\pi} \log_e\left(\frac{d}{2\pi a}\right)$$

where a = radius of wire in mm

d = distance of free space

μ_0 = permeability of free space

To cancel the impedance due to the dielectric by the impedance of a grating

$$1/Z_1 + 1/Z_2 = 0$$

With a dielectric thickness of 8 mm and relative permittivity 4·5, we find that at 650 MHz if d = 100 mm, then a = 0·006 mm. Wire of this diameter would be inconveniently thin and there would be some risk of burning out.

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